COMPARATIVE STUDY OF VESTA AND CERES INTERIORS BASED ON THE DAWN MISSION GRAVITY AND TOPOGRAPHY MEASUREMENTS

Asteroids, Comets, Meteorites 2017
Montevideo, Uruguay
April 10-14, 2017

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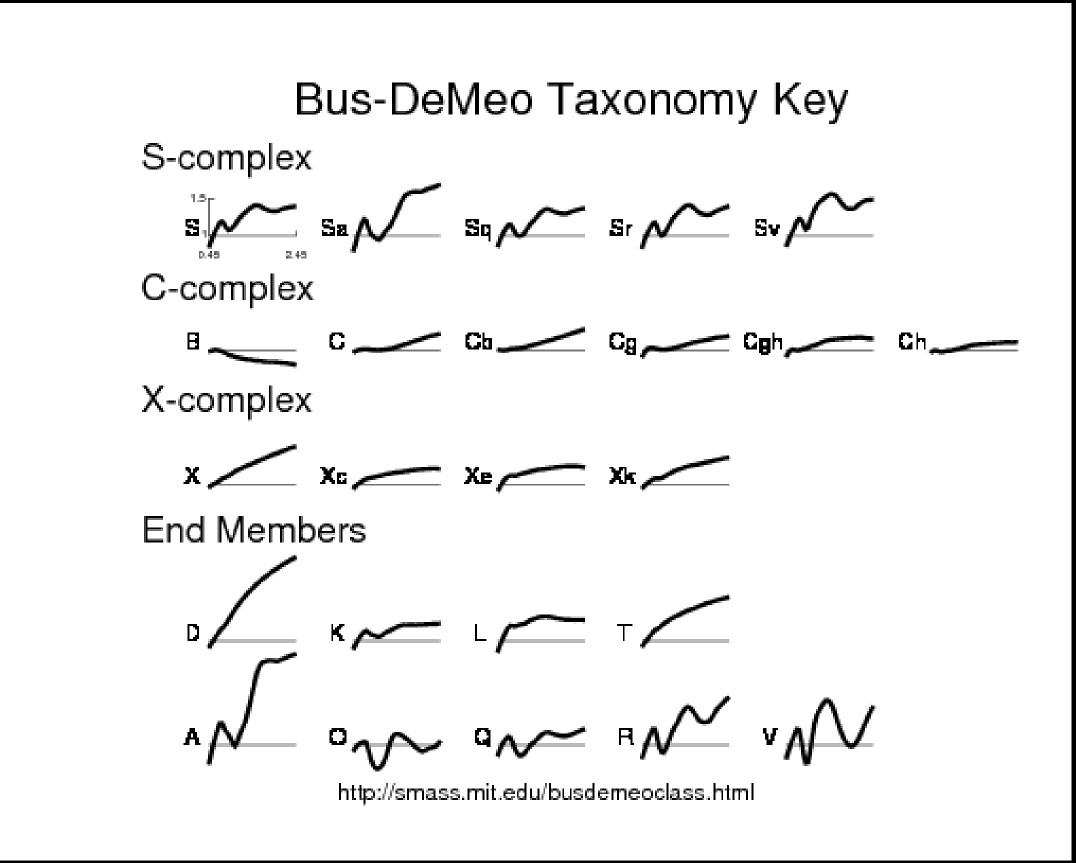
Outline

- Why Vesta?
- What we learned about Vesta's interior from gravity and topography
- Why Ceres?
- What we learned about Ceres' interior from gravity and topography
- Compare evolutions of Vesta and Ceres
- Summary of findings

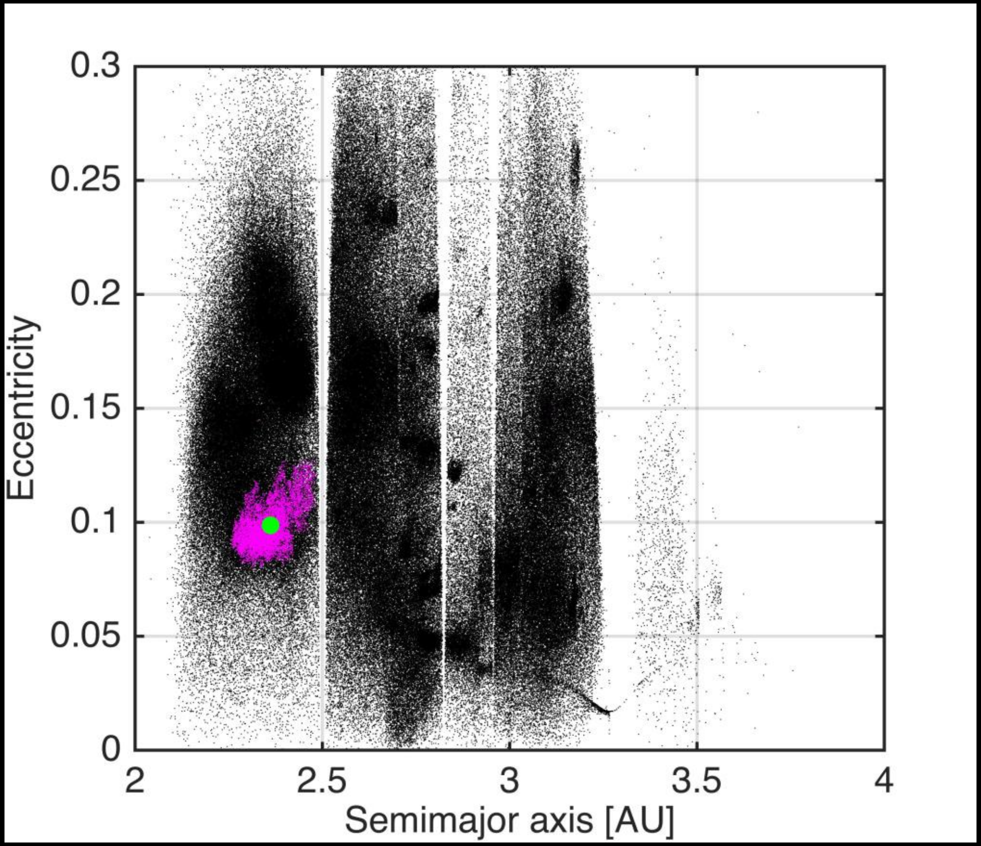
Why Vesta?

- **Unique basaltic spectrum**



Why Vesta?

- **Unique basaltic spectrum**
- **A group of asteroids in the dynamical vicinity of Vesta with similar spectra**



Why Vesta?

- **Unique basaltic spectrum**
- **A group of asteroids in the dynamical vicinity of Vesta with similar spectra**
- **Large depression in the southern hemisphere of Vesta**

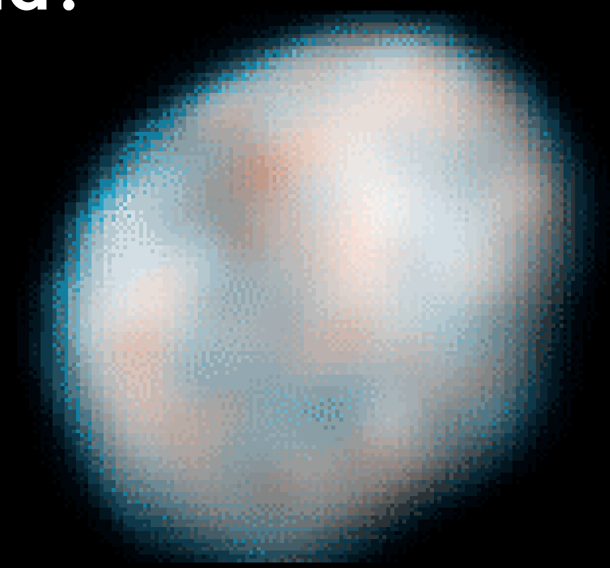
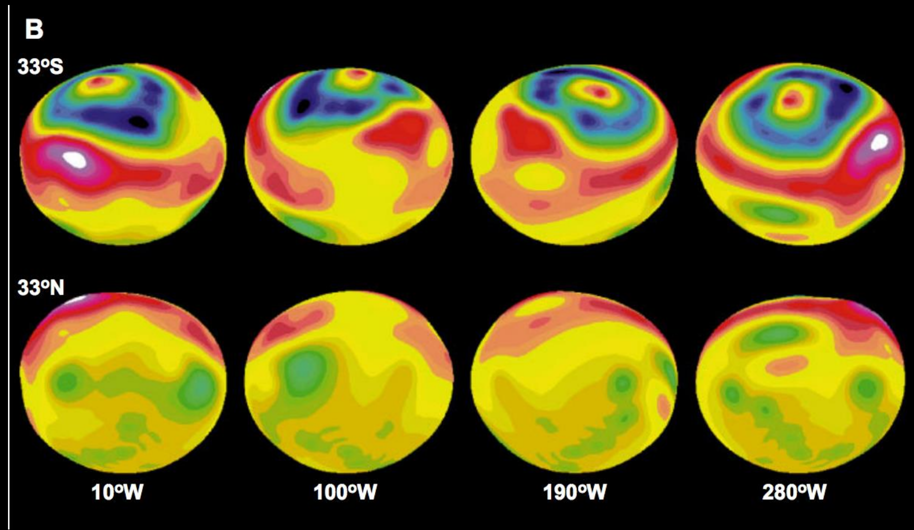


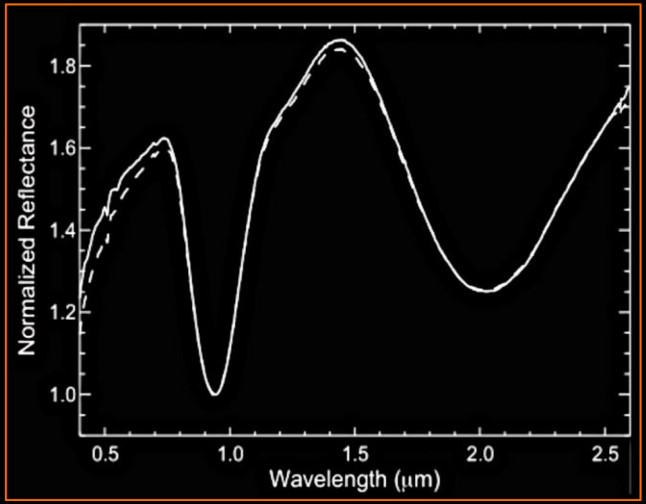
Image credit: NASA/HST



Thomas et al., 1997

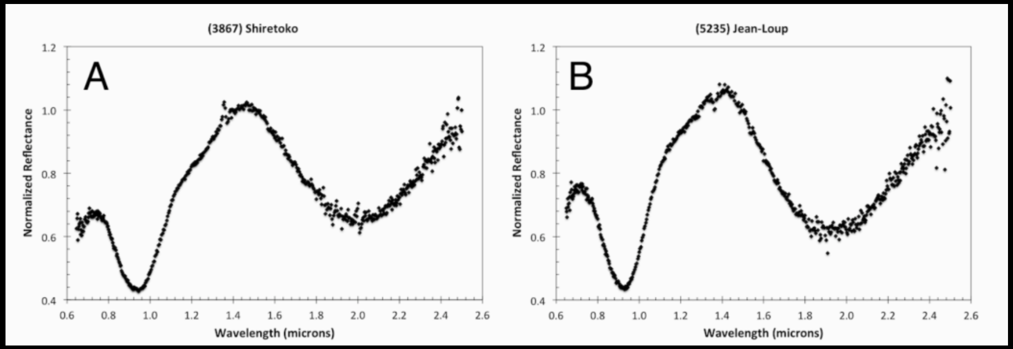
Why Vesta?

- Unique basaltic spectrum
- A group of asteroids in the dynamical vicinity of Vesta with similar spectra
- Large depression in the southern hemisphere of Vesta
- A group of Howardite-Eucrite-Diogenite (HED) meteorites, with similar reflectance spectra



↑ Reflectance spectra of eucrite Millbillillie from Wasson et al. (1998)

↓ V-type asteroids spectra from Hardensen et al., (2014)



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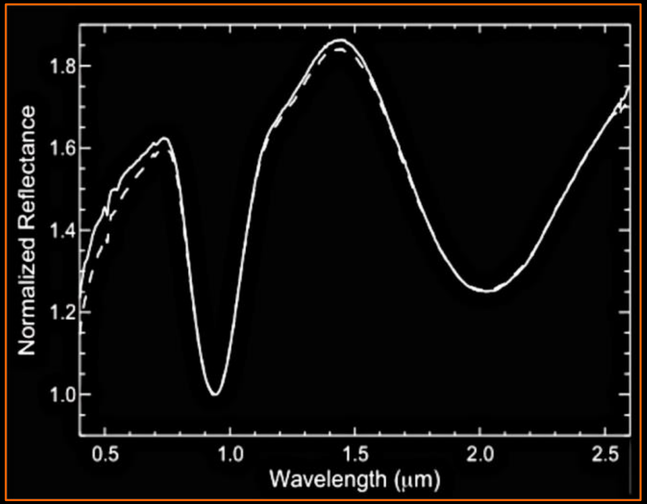
- A group of Howardite-Eucrite-Diogenite (HED) meteorites, with similar reflectance spectra
- Strongest connection between a class of meteorites and an asteroidal family



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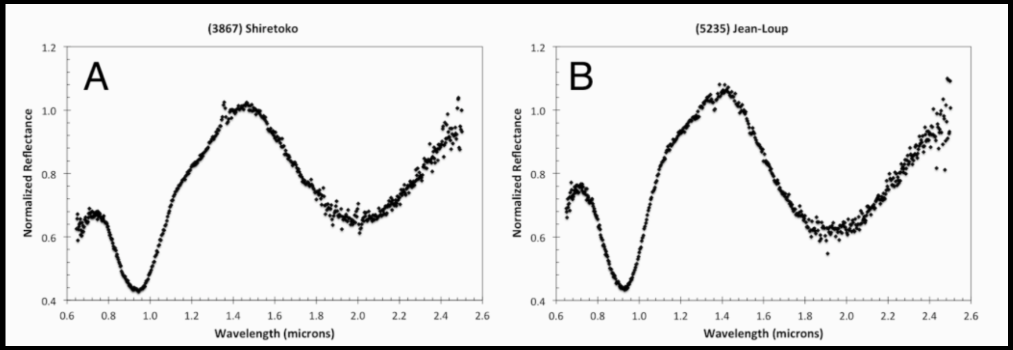
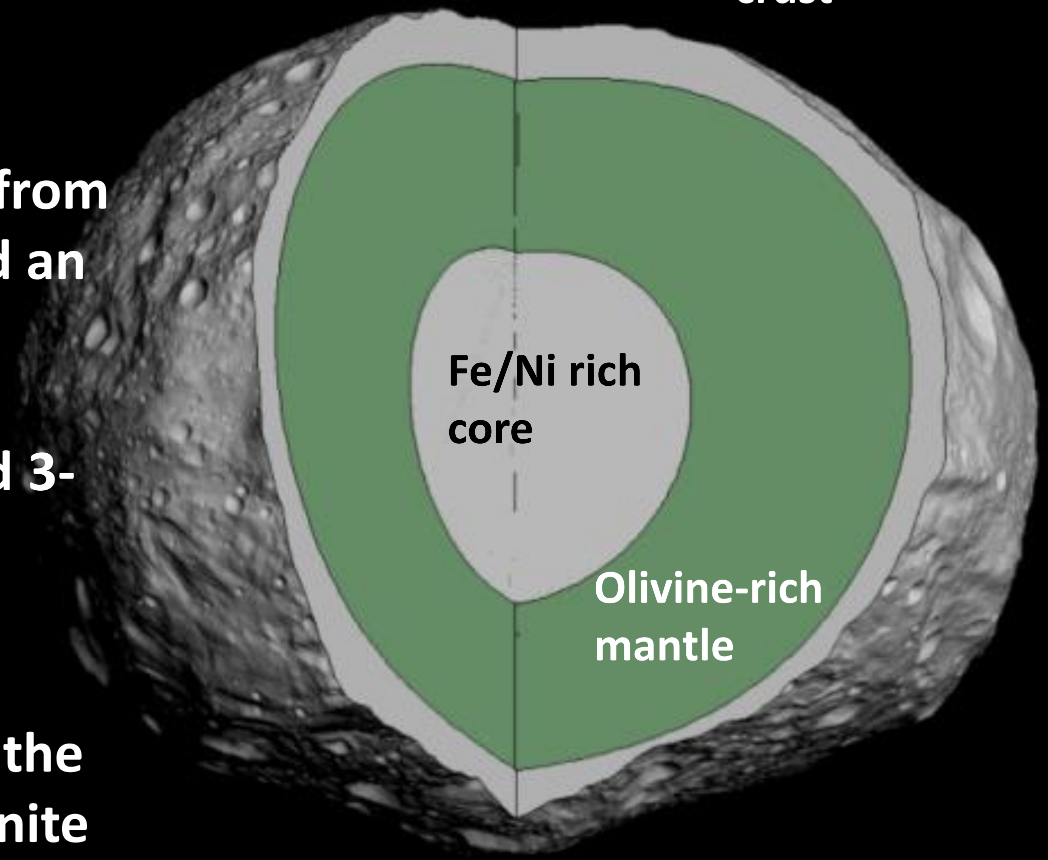
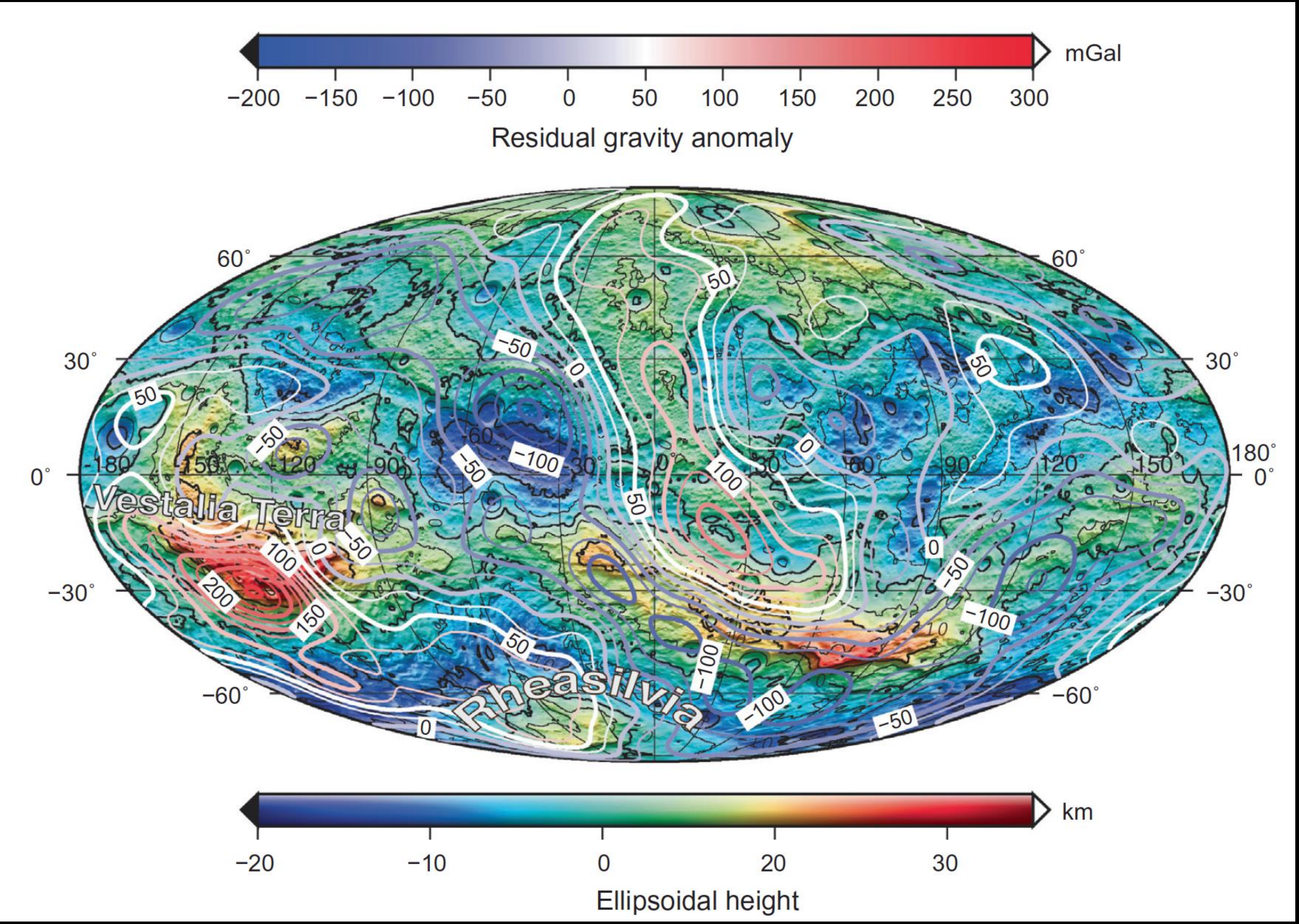


Interior structure modeling

- Vesta is not presently in hydrostatic equilibrium
- No unique solution **only** from gravity/topography, need an extra constraint
- Geochemically motivated 3-layer interior structure (Ruzicka et al., 1997)
- Densities constrained by the Howardite-Eucrite-Diogenite (HED) meteorites



Bouguer Anomaly

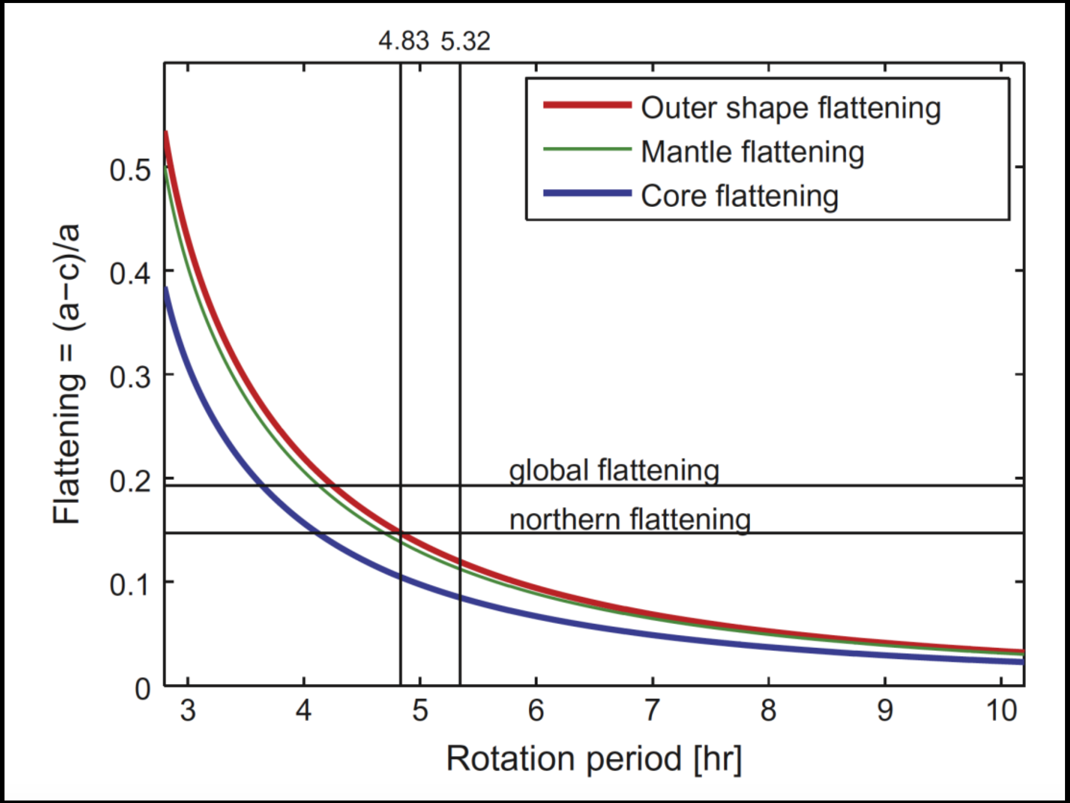


Ermakov et al., 2014

Key results from thermal and impact modeling

- Vesta was likely close to hydrostatic equilibrium in its early history
- Major impact occurred when Vesta was effectively non-relaxing
- The areas >50° away from major impacts were not significantly deformed
- Crater counting reveals that the northern Vesta terrains are old (>3Gy)

- Northern terrains likely represent the pre-impact shape of Vesta.



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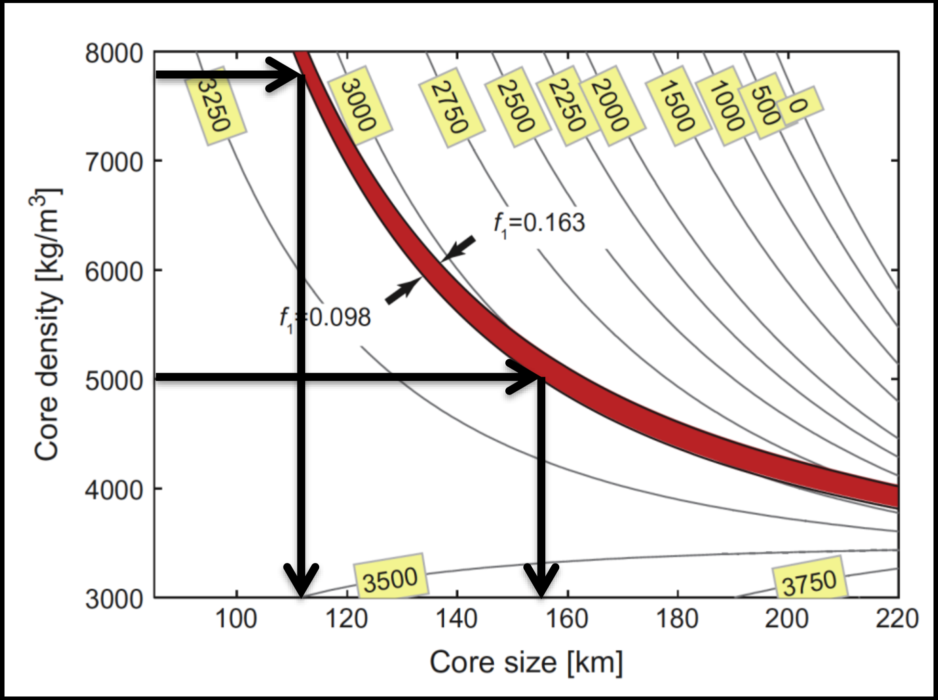
Contours are mantle density [kg/m^3]



Core radius of 110 to 155 km

Ceres

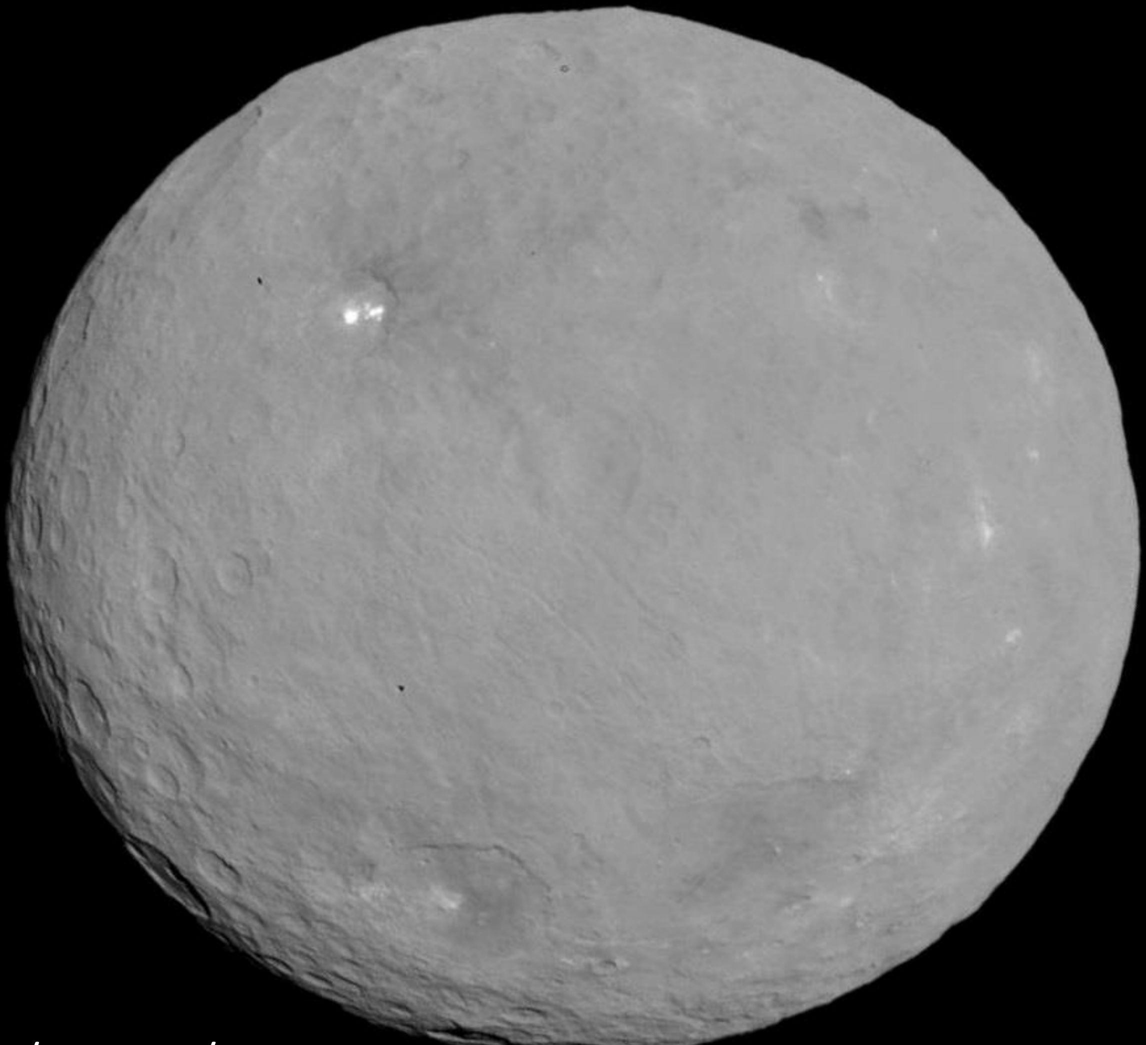
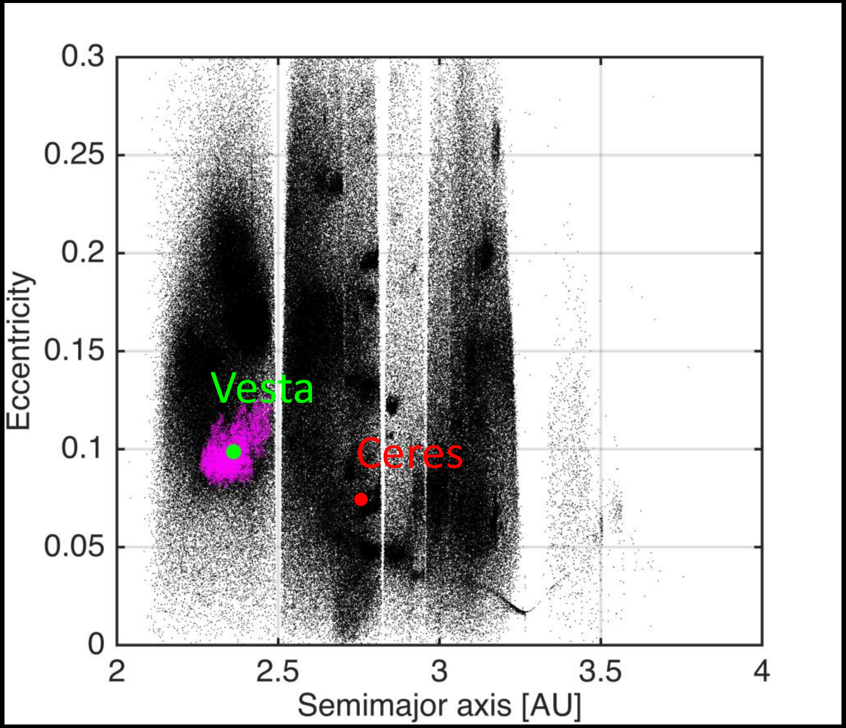


Image credit: NASA/JPL, DLR/MPS

Why Ceres?

- **Largest body in the asteroid belt**
- **Low density implies high volatile content**
- **Conditions for subsurface ocean**
- **Much easier to reach than other ocean worlds**



What did we know before Dawn

- **Castillo-Rogez and McCord 2010**

  Ceres accreted as a mixture of ice and rock just a few My after the condensation of Calcium Aluminum-rich Inclusions (CAIs), and later differentiated into a water mantle and a mostly anhydrous silicate core.

- **Zolotov 2009**

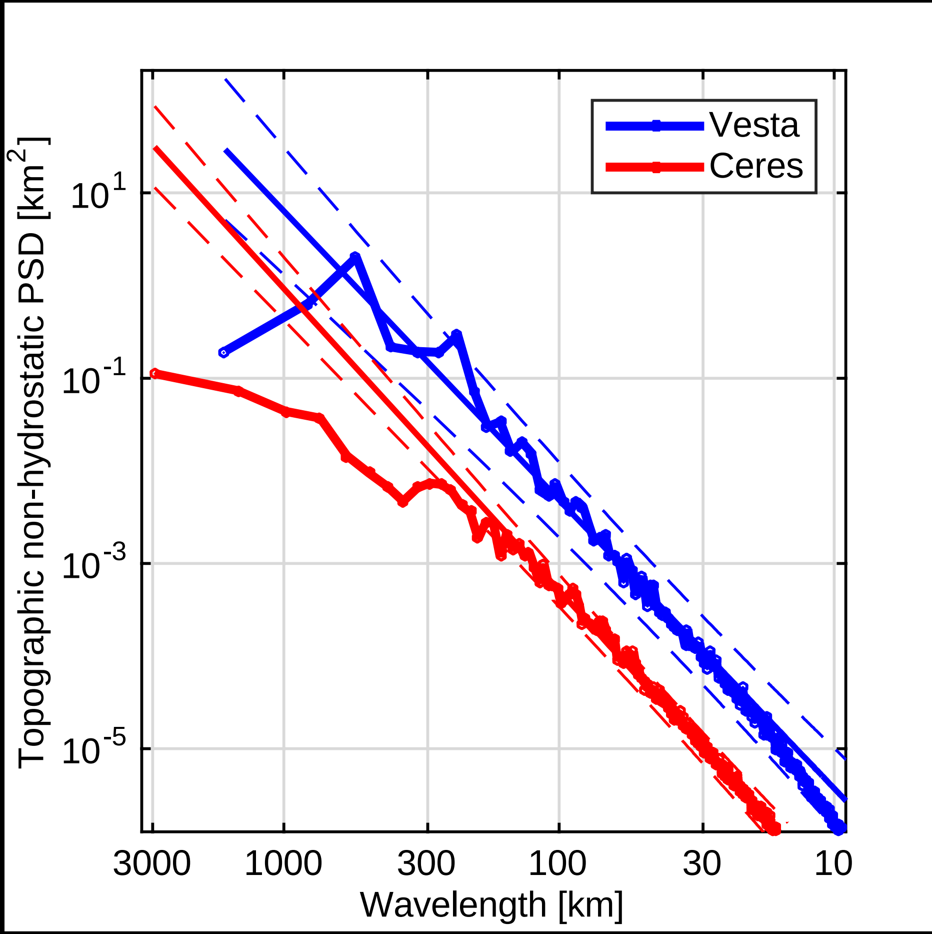
  Ceres formed relatively late from planetesimals consisting of hydrated silicates.

- **Bland 2013**

  If Ceres *does* contain a water ice layer, its warm diurnally-averaged surface temperature ensures extensive viscous relaxation of even small impact craters especially near equator

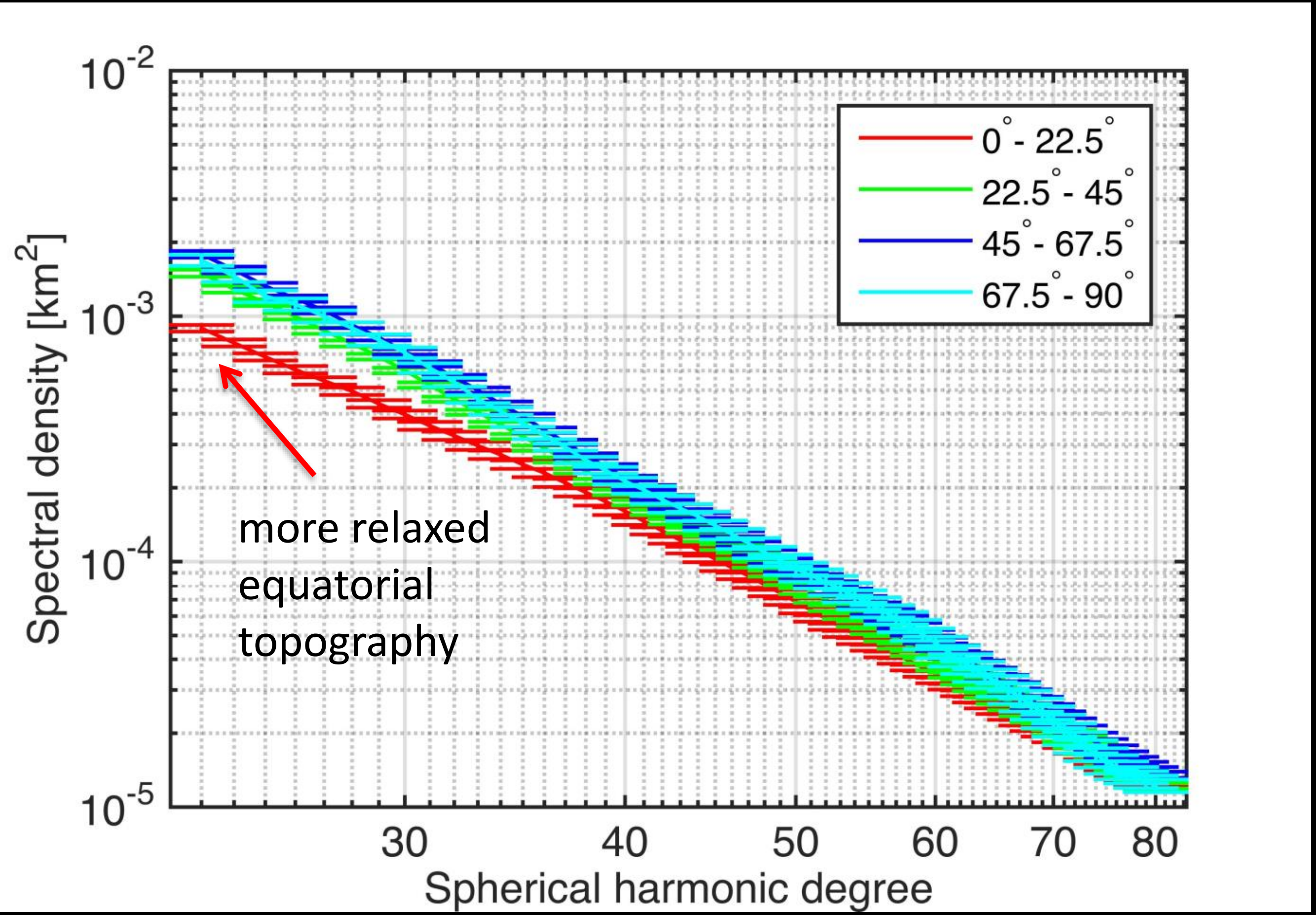
Evidence for viscous relaxation

- **More general approach: study topography power spectrum**
- **Power spectra for Vesta closely fits with the power law to the lowest degrees (λ < 750 km)**
- **Ceres power spectrum deviates from the power law at λ > 270 km**



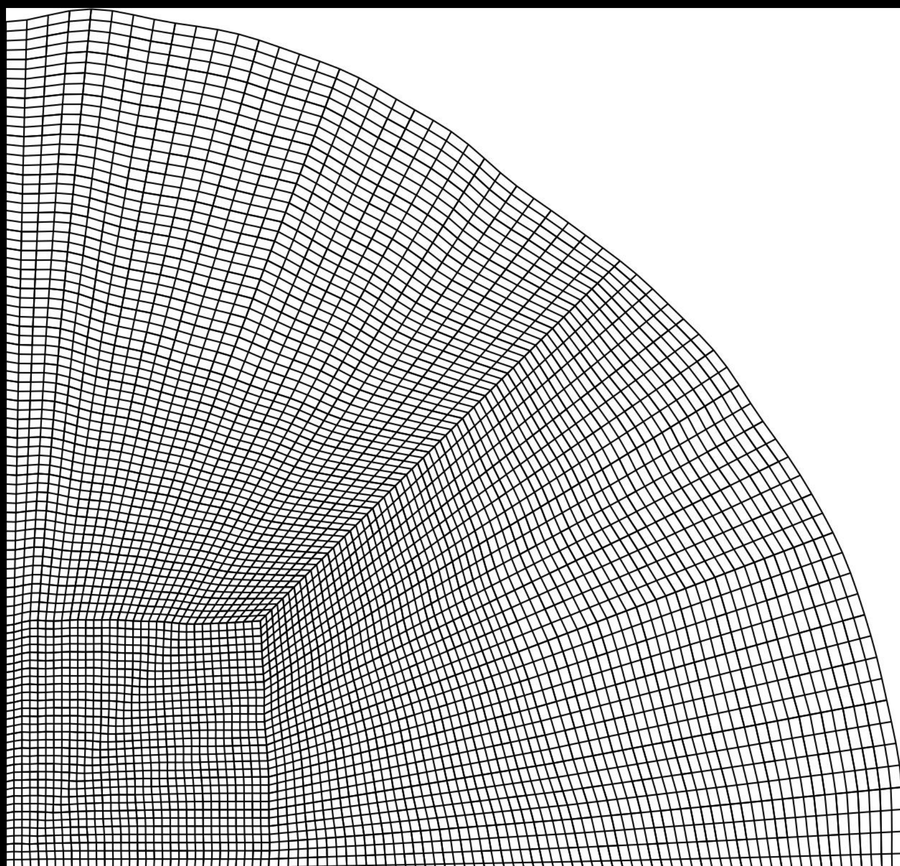
Ermakov et al,. in prep

Latitude dependence of relaxation



Ermakov et al., in prep

Finite element model



Fu et al., 2014; Fu et al, submitted to EPSL

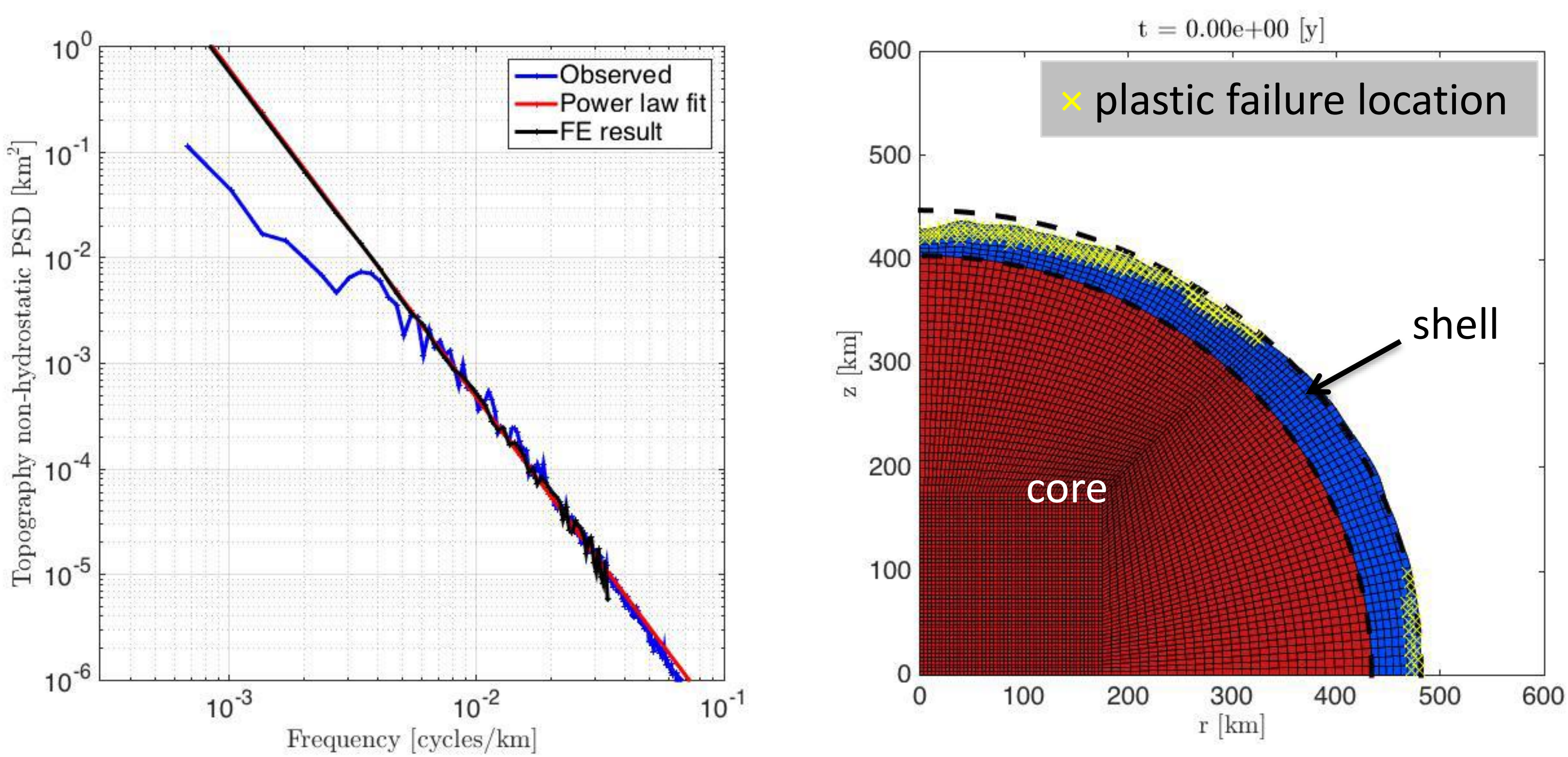
- **Assume a density and rheology structure**
- **Solve Stokes equation for an incompressible flow using deal.ii library**

$$\partial_i(2\eta\dot{\varepsilon}_{ij}) - \partial_i p = -g_i\rho$$

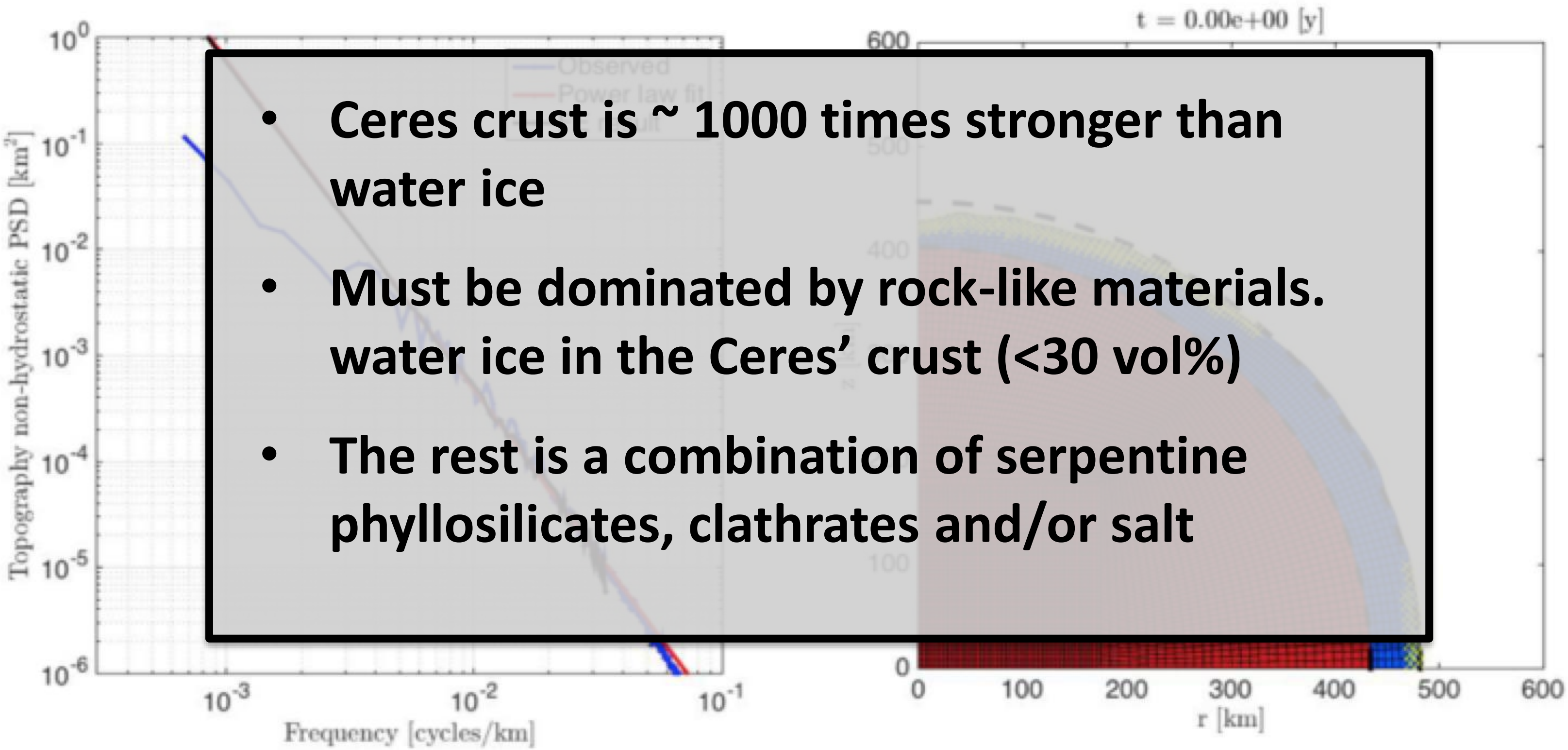
$$\P_i u_i = 0$$

- **Compute the evolution of the outer surface power spectrum**

Example of a FE modeling run



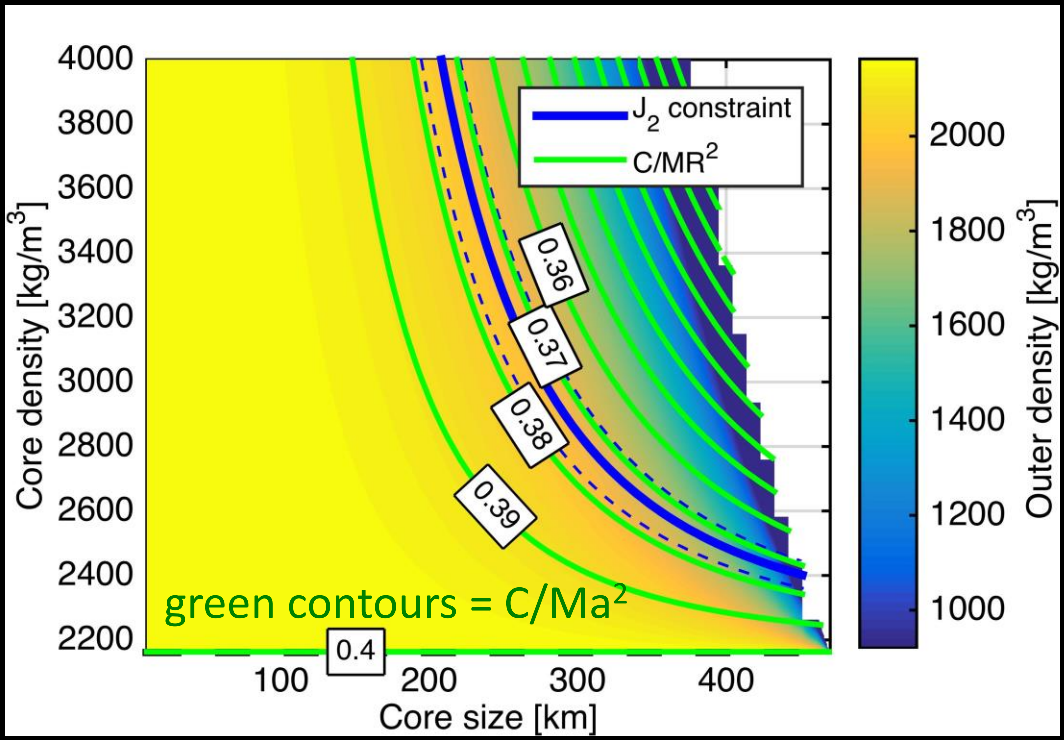
Finite element modeling results



- **Ceres crust is ~ 1000 times stronger than water ice**
- **Must be dominated by rock-like materials. water ice in the Ceres' crust (<30 vol%)**
- **The rest is a combination of serpentine phyllosilicates, clathrates and/or salt**

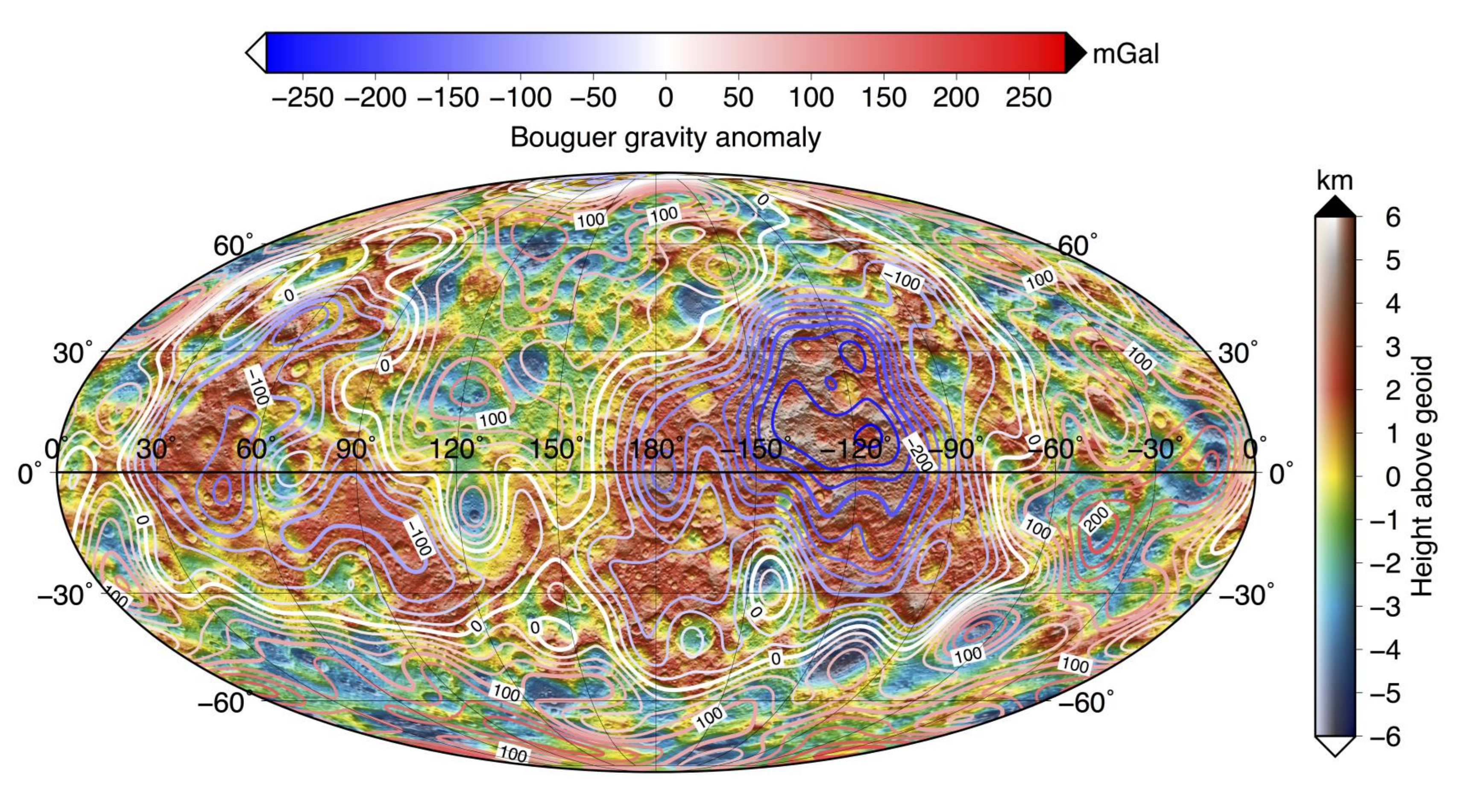
Two-layer model

- **Simplest model to interpret the gravity-topography data**
- **Only 5 parameters: two densities, two radii and rotation rate**
- **Yields $C/Ma^2 = 0.373$ $C/M(R_{vol})^2 = 0.392$**



Using Tricarico 2014 for computing hydrostatic equilibrium

Bouguer anomaly



Ermakov et al.,
submitted to JGR

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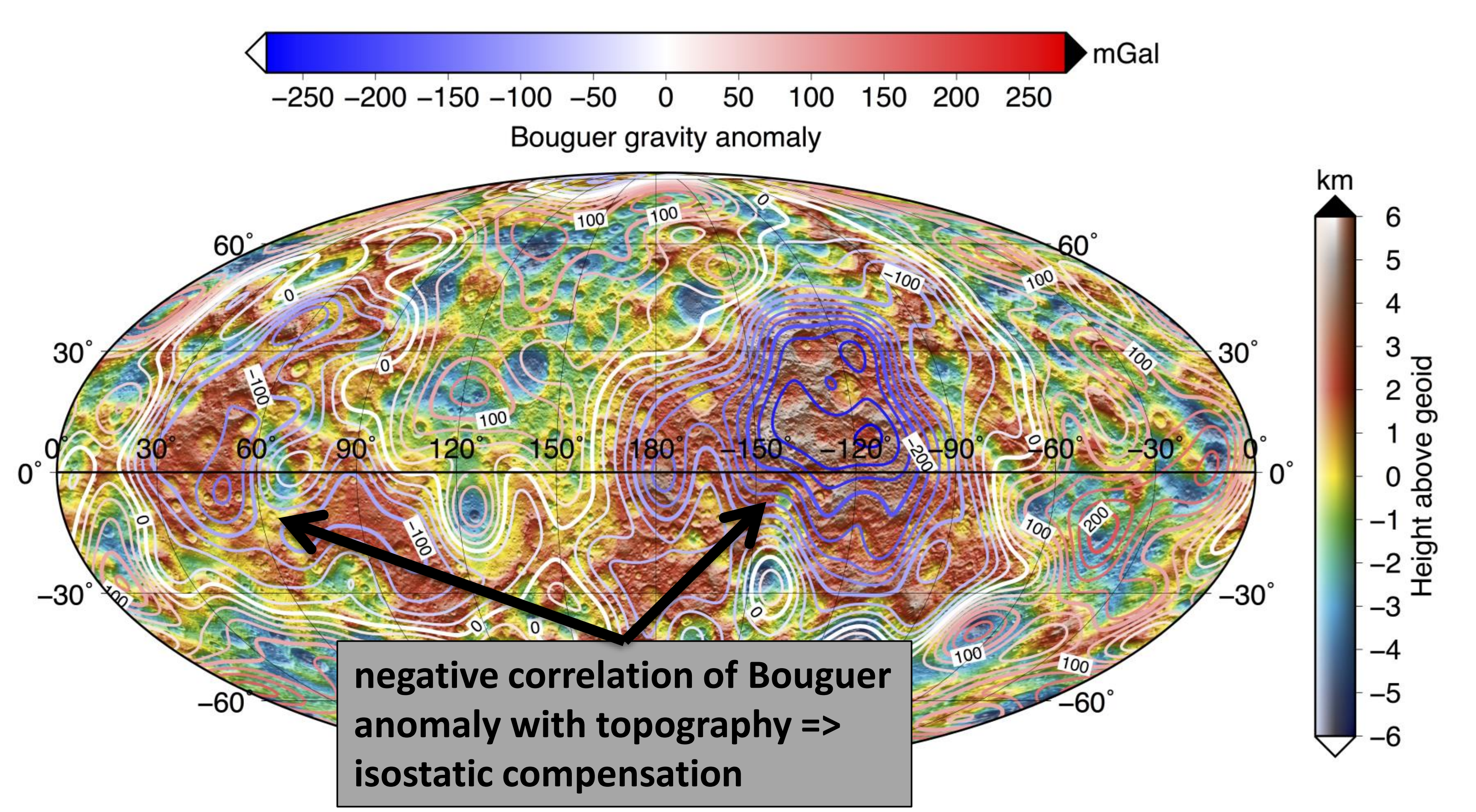

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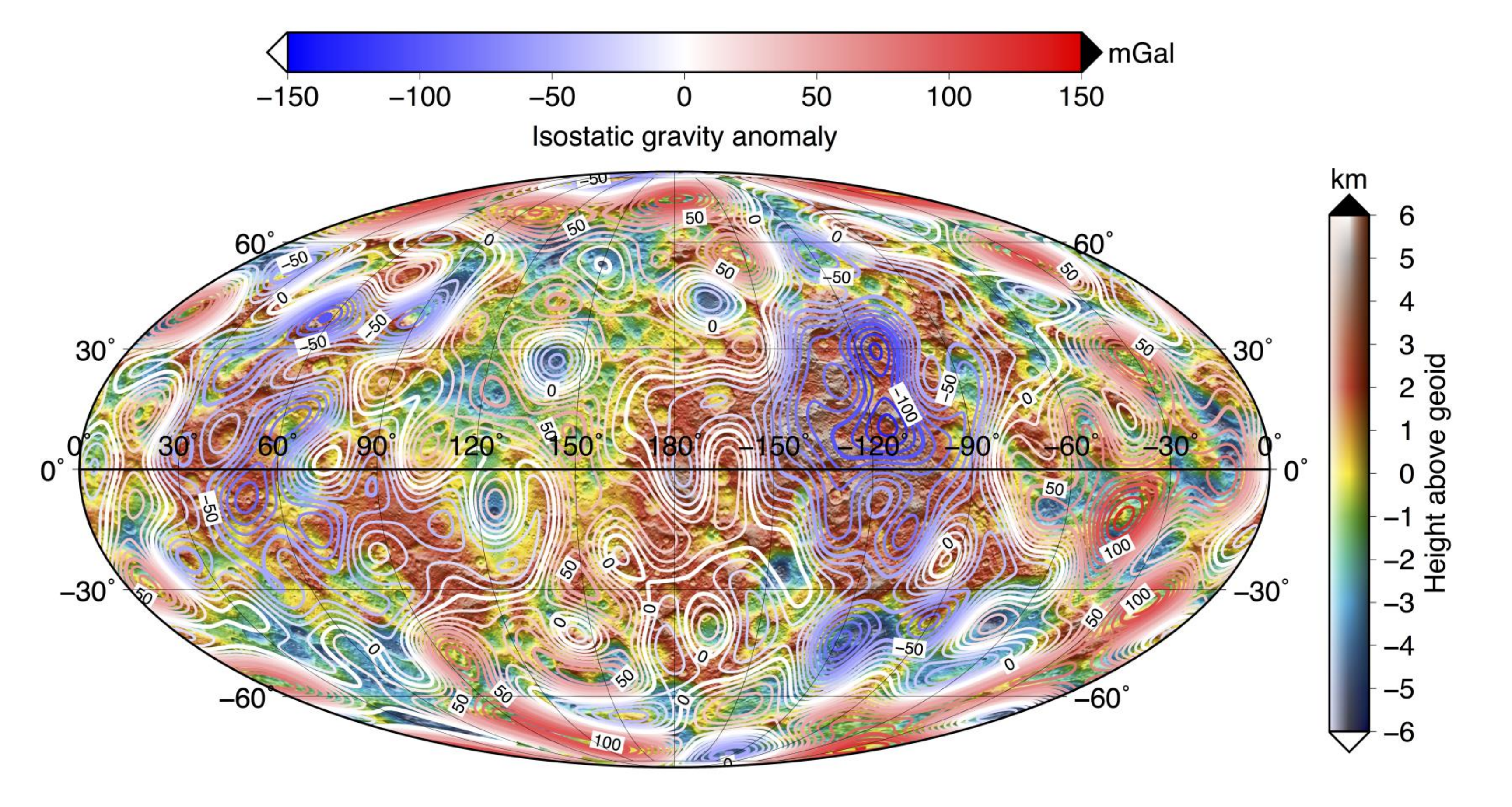
Isostatic anomaly



Ermakov et al.,
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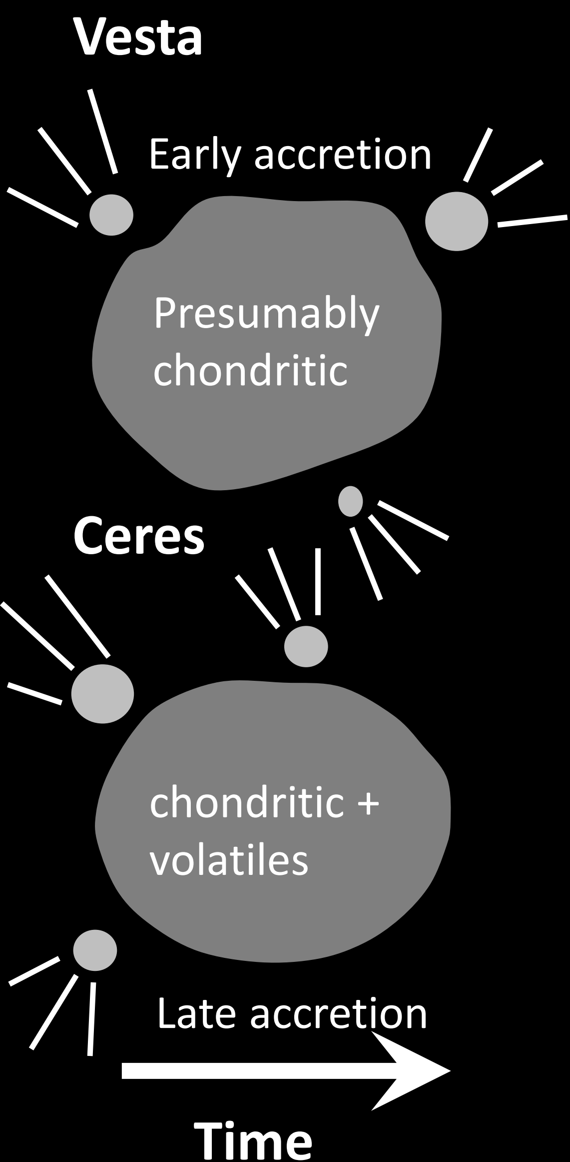
Vesta and Ceres comparative evolution



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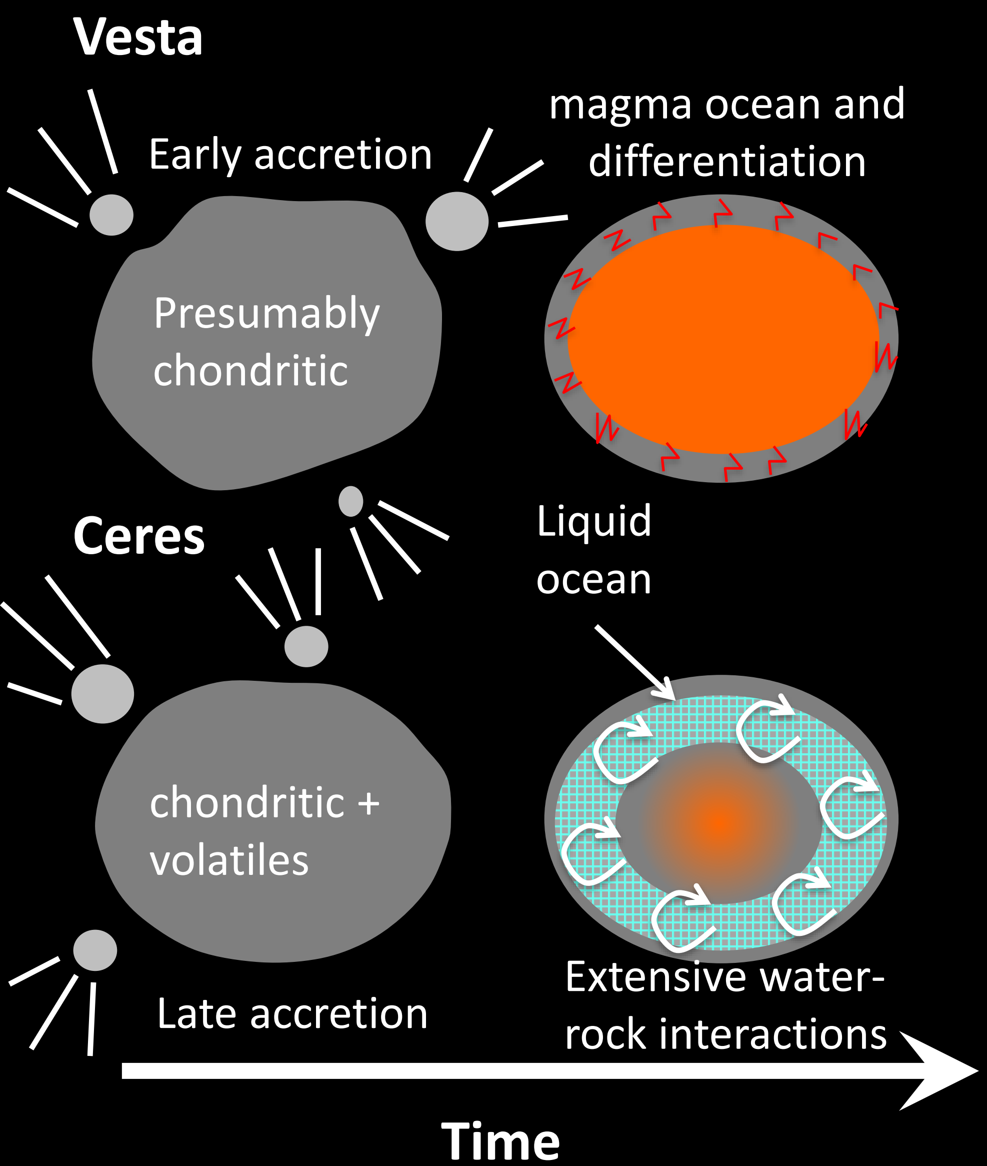

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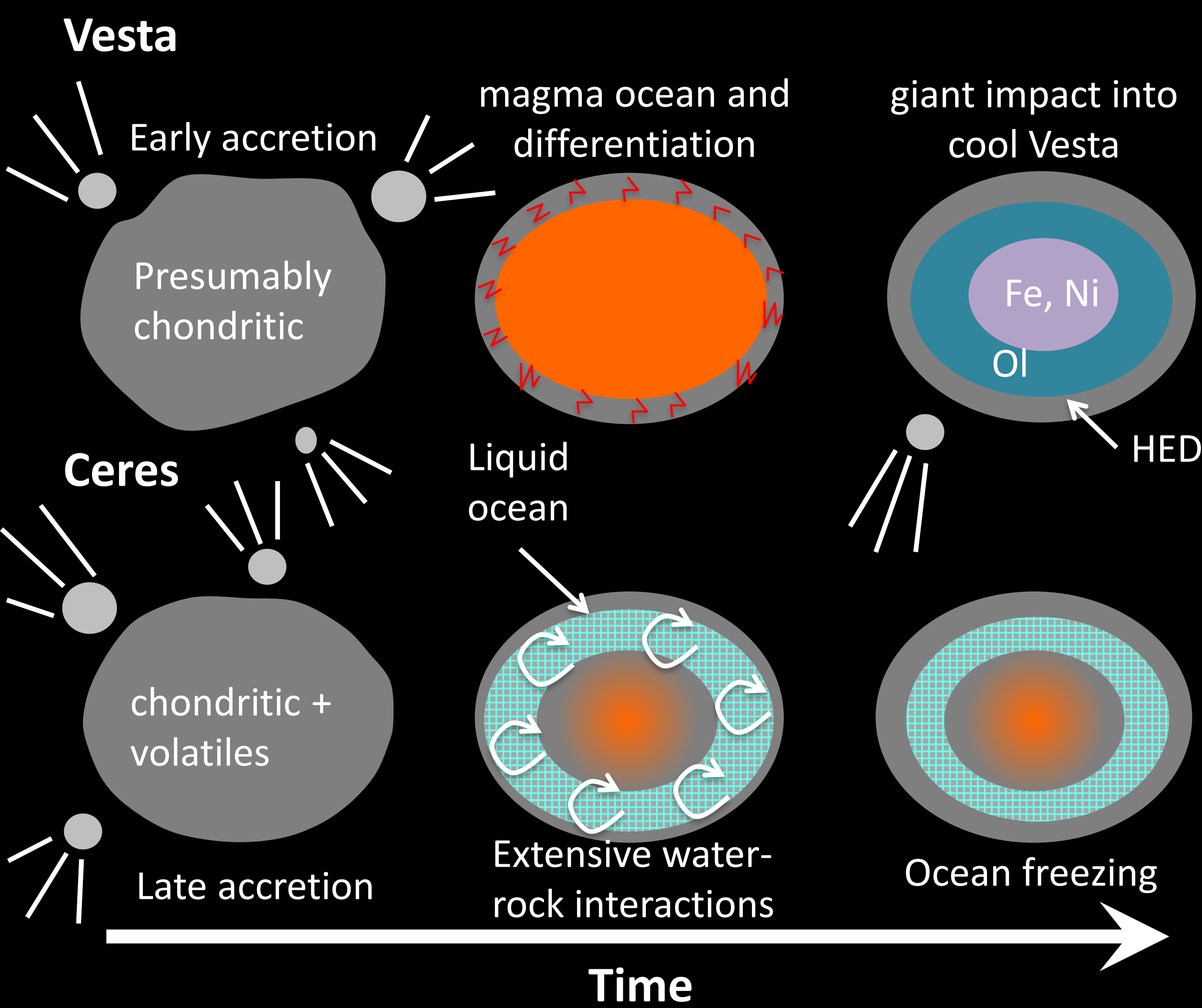

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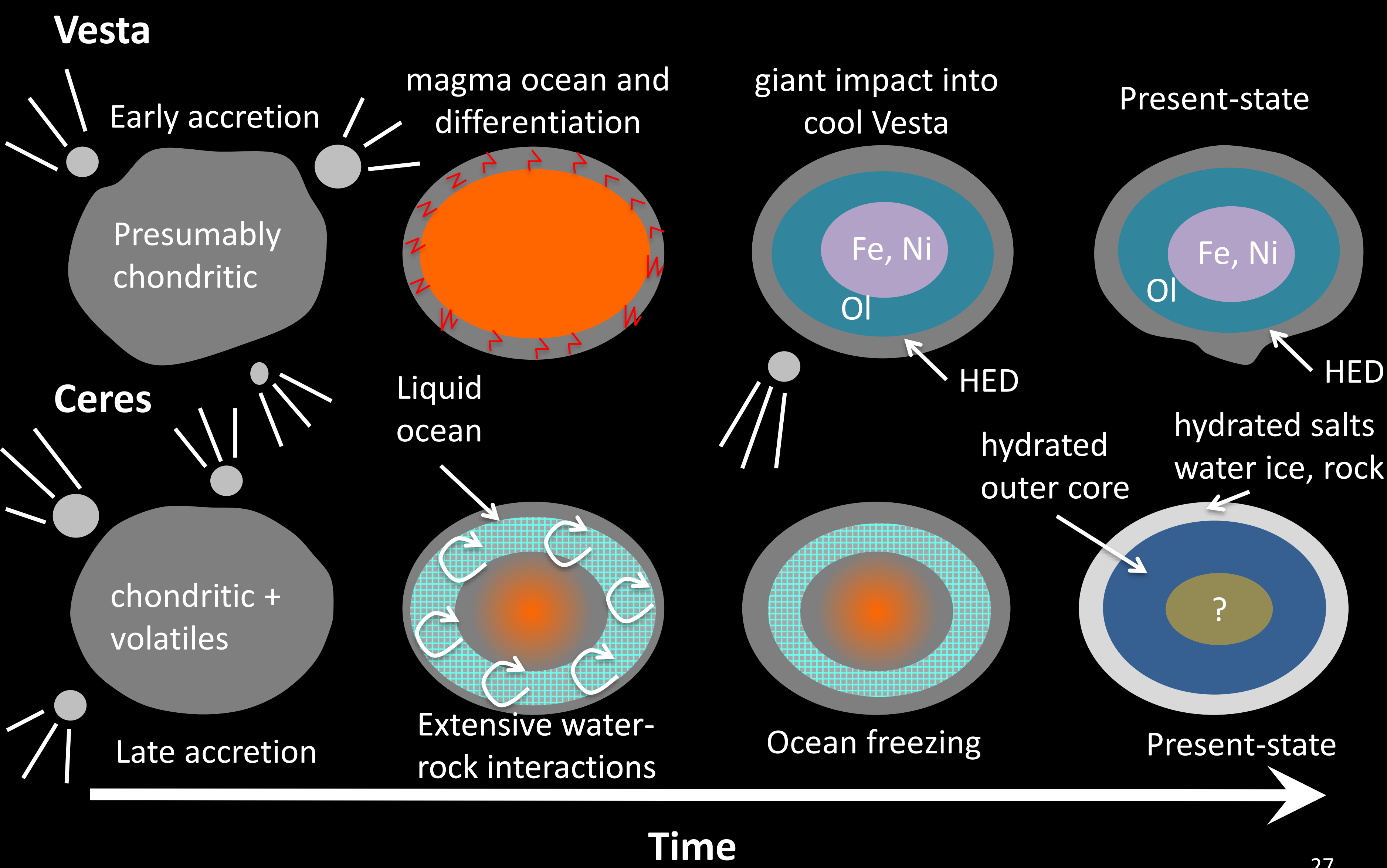
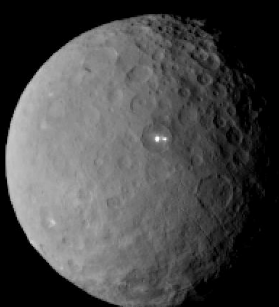


Summary

- Formed early (< 5 My after CAI)
- Once hot and hydrostatic, Vesta is no longer either
- Differentiated interior
- Most of topography acquired when Vesta was already cool => uncompensated topography
- Despun by two giant collisions
- Combination of gravity/topography data with meteoritic geochemistry data provides constraints on the internal structure



- Formed late (> 5 My after CAI)
- Partially differentiated interior
- Developed a subsurface ocean in the past
- Experienced limited viscous relaxation
- Much lower surface viscosities (compared to Vesta) allowed compensated topography
- Ceres' crust is light (based on admittance analysis) and strong (based on FE relaxation modeling)
- Not much water ice in Ceres crust (<30 vol%) now